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ABSTRACT

This paper is predicated on the realization that a chemical hood is only one element of laboratory safety which encompasses a variety of other elements starting with the architectural design and layout of laboratories; through the installation, operation and maintenance of integrated electrical and mechanical systems; to the safety-mindedness of the individuals performing the work in these hoods and the impact of fume hoods on indoor air quality. Personal safety must be the overriding consideration at each fume hood and must dictate appropriate design, installation, and operational protocols. The compilation and promulgation of such criteria are the principal objectives of this paper which is based on a review of the existing Board of Regents of the University System of Georgia "Design Criteria." When implemented these electrical, mechanical, and human control guidelines should promote the continued safety of students, faculty members, and staff members who design, operate, and maintain chemical fume hoods in the academy in general and in the Regent's System in particular. Topics covered include: historical perspective, recent fume hood application trends, fume hood manufacturers and laboratory furniture manufactures, general and specific recommendations, observations and additional suggestions, and conclusions. Contains 8 endnotes and 23 references. (JRH)

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Chemical Fume Hoods in Higher Education Science Laboratories: Electrical, Mechanical and Human Controls

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The University of Georgia
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Chemical Fume Hoods in Higher Education Science Laboratories: Electrical, Mechanical and Human Controls

Forward

This paper is predicated on the realization that a chemical fume hood is only one patch on the quilt best described as "Laboratory Safety" in higher education science laboratories. Many other elements define and complement this mosaic, starting with the architectural design and layout of laboratories, through the installation, operation and maintenance of integrated electrical and mechanical systems, to the safety-mindedness of the individuals performing work in these hoods and the impact of fume hoods on indoor air quality.[1] In some buildings an occasional fume hood or two places minor constraints on building designers and operators. In the case of teaching and research science facilities, however, the entire programmatic design thrust ' .. the accommodation of scores of these fume hoods. In both instances, personnel safety must be the overriding consideration at each fume hood, and must dictate appropriate design, installation and operational protocols. The compilation and promulgation of such criteria are the principal objectives of this paper, which is based on a review of existing Board of Regents of the University System of Georgia Design Criteria. When implemented, these electrical, mechanical and human control guidelines should promote the continued safety of students, faculty members and staff members who design, operate and maintain chemical fume hoods in the academy in general, and in the Regents's System in particular.

Historical Perspective - Georgia Board of Regents's Criteria

In September 1974, the Board of Regents sent copies of their proposed Design Criteria for Laboratory Furniture to System campus architects for review and comments. At that time, three types of fume hoods - general purpose, radiation and perchloric acid - were recommended, with three manufacturers "approved." Glove boxes were mentioned for use in certain special procedures, but were not otherwise identified or described. Biological safety cabinets and laminar flow hoods were not mentioned in this or subsequent revisions to the criteria. A schedule showing variations on the three types of hoods indicated that in full open position a face velocity of 150 FPM was required for radiation and perchloric hoods, while 125 FPM was required for general purpose hoods. This Design Criteria was promulgated on February 1, 1975.

During the 1980's, several modifications were made to the Criteria, until the latest version dated December 1, 1987 was published. These Criteria indicate that face velocity requirements were reduced to 125 FPM for radiation and perchloric acid types, while a general purpose hood's face velocity was reduced to 100 FPM. Seven fume hood manufacturer's were "approved" in this document, which covers the entire spectrum of laboratory furniture.

In addition to Design Criteria for Laboratory Furniture, the Regents publish Mechanical Design Criteria. These were printed in 1971, and include specific directives regarding fume hood ventilation requirements. Both the Perchloric and Hot Nitric Acid section and the General Purpose and Radioisotope section of these criteria direct that:

a) all exhaust ductwork, except the 90 degree elbow at the fan inlet, be vertical with no offsets.

b) all fume hoods shall have an individual fan and exhaust duct.

c) all fume hood exhaust fans shall be located on the building roof.

d) perchloric and nitric acid hoods shall have a wash-down system.

e) exhaust ductwork shall be 16 gage stainless steel with welded and ground smooth joints.

f) Radioisotope hoods shall have a HEPA filter section in the exhaust duct.

The Mechanical Criteria included a chart showing fume hood air requirements based on full open position sashes, with 125 FPM face velocities for perchloric acid and radioisotope hoods, and a 100 FPM face velocity for general purpose hoods. At the University of Georgia, the Chemical Laboratory Safety Manual (currently being revised) promoted these and other safety-related regulations since the 1970s.

To summarize, the principal fume hood requirements for a Board of Regents's project were very specific, were written in a form which did not suggest that exceptions were allowed, and did not differentiate between new construction and renovation projects.

Recent Fume Hood Application Trends

Recently, several factors have forced building designers, manufacturers, owners and operators of chemical fume hoods to reevaluate their positions regarding these safety devices. Concerns for increased personnel safety, energy conservation, improved indoor air quality and potential liability exposure have changed significantly the ground rules for fume hood applications, including those in a higher education setting. For example, building control systems have recently become available which can integrate fume hood ventilation with the rest of the building's requirements, so that appropriate pressure differentials and face velocities are maintained within acceptable limits at all hoods during all occupied hours.[2]

Building designers and owners, then, should begin planning to furnish such state-of-the-art systems to protect the personnel using these hoods in all new structures.[3] In addition, manifolded or "ganged" exhaust systems have been installed in many laboratories; these systems employ a large plenum which collects individual exhaust ducts from many fume hoods, and uses several large fans (with redundancy) to exhaust the fumes to the atmosphere.[4] As an owner with several thousand fume hoods in its facilities, the Regents's should consider revising guidelines to reflect the changes that have occurred in the past 20 years, and to take advantage of the improved safety and energy conservation features which are now becoming available.

Fume Hood Manufacturers and Laboratory Furniture Manufacturers

Major suppliers of chemical fume hoods on recent Board of Regents's projects at the University of Georgia include Kewaunee Scientific Corporation, Hamilton Corporation, and Air Master Systems Corporation. Each manufacturer offers hoods to suit most applications, including conventional, radioisotope and perchloric acid types. Some hood manufacturers, especially smaller companies, are members of The Scientific Equipment and Furniture Association, or SEFA; this group publishes "Laboratory Fume Hoods - Recommended Practices - SEFA 1.1-1994" which promulgates design and operation parameters with which all members comply. The hood performance testing protocols recommended by SEFA are not identical to those recommended in ANSI/ASHRAE Test 110, but appear to be appropriate for field testing.[5]

Not all laboratory furniture manufacturers have a line of fume hood products. As a result, a legitimate furniture manufacturer such as Leonard Peterson Company generally offers a bid on a construction contract which includes the cost of a fume-hood-only manufacturer's products (such as Air Master). Since a vast majority of such construction contracts are based on Constructions Specifications Institute, or CSI, format, this usually results in a "casework subcontractor" specified in Section 14 who furnishes and installs all laboratory furniture, including fume hoods and companion fume hood blowers, but who does not install fume hood ductwork and ventilation system controls. It may prove more prudent in the future to require fume hoods and blowers to be specified in the Mechanical (Section 15) portion of the specification, so that this ventilation equipment would be installed by the mechanical subcontractor. If this were done, the responsibility for complete air balance and commissioning of the HVAC system would be vested in the mechanical subcontractor, including all fume hood field testing and balancing.[6]

Recommendations - General

The Board of Regents should consider a major revision to Design Criteria for Laboratory Furniture for all new construction or major (i.e. complete gutting and rebuilding) renovation projects. This revision could be prepared in two short Sections: Design Criteria and Approved Manufacturers. The Design Criteria Section should refer the Architect to a list of design reference works and codes to establish minimum safety, clearance, modular spacing, equipment types, etc. requirements for various laboratory applications. The Design Section should also indicate minimum fume hood sizes (and ventilation rates) for each laboratory type. Generic floor plans could be developed as a guide for architects, recommending modular design criteria and indicating preferred locations for hoods, emergency showers, exits, flammable storage cabinets, etc. Using these guides, the architect should proceed to design functional laboratories for each project, utilizing equipment listed in the approved Manufacturers Section. Finally, all other laboratory minor renovation projects should be treated on an individual case basis; exceptions to the Design Criteria should be allowed, based on a positive risk assessment prepared by the designers and operators.

Subsequent to the adoption of these new Criteria, the balance of the Regents's standard specification and design requirements should be revised or rewritten to reflect standard practices in the academy. Also, the Preventive Maintenance Manual developed in the 1980s should be updated to include both preventive and repair/replacement maintenance procedures for fume hood blower systems. Finally, specific design, operation and maintenance procedures should be developed and promulgated for Biological Safety Cabinet systems of all types.

Recommendations - Specific

Based on a review of the literature on laboratory safety and fume hoods, [7] the publication American National Standard for Laboratory Ventilation (ANSI/AIHA Z 9.5-1992), which indicates appropriate electrical, mechanical and human controls, should be cited as the basis for all laboratory design for Board of Regents's projects, with the following exceptions or additions: [8]

1. Fume hoods handling radioisotopes should be divided into two categories:

   A) Low level hoods - these are hoods subjected to minimum levels of radioactive materials. Such hoods should be constructed with stainless steel coved liners for wipedown, but should not be equipped with a HEPA filter. Low level hoods would be installed similar to Class A

Chemical Hoods. Researchers should be encouraged to employ minimum levels of radioactive materials in their experiments whenever possible.

B) High level hoods - such hoods would be subjected to higher levels of radioisotopes. These hoods would be stainless steel lined and be equipped with HEPA filters on the outlet. A face velocity in excess of standard would be allowed, but in no case would this exceed 125 FPM. (Section 1.1). Researchers should be discouraged from employing such higher levels of radioisotopes unless this is absolutely necessary.

2. Kjeldahl digestion unit, gas chromatograph unit and atomic absorption unit ventilation systems should be designed in accordance with ACGIH recommendations; standard sketches should be included for these two systems. All-PVC or induction-type blowers should be required for Kjeldahl units. (Section 1.1)

3. All references to Code of Federal regulations (CFRs) should be qualified to indicate that the Regents are not adapting these as requirements, but only as guides. (Section 2; passim)

4. Auxiliary air hoods should not be permitted on new construction or major renovation projects, but should be considered on minor renovation projects. (Section 3.1)

5. Laboratory Ventilation Management Program should be System-Wide, with specific individuals appointed at each unit to promulgate and maintain the

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program. (Section 4.3)

6. Reference here, and in any subsequent paragraph, to OSHA should be modified as in (3) above, since OSHA does not have jurisdiction over Georgia State Agencies. (Section 4.3)

7. Discharge velocity from blowers should be increased from 3000 to 4000 FPM. (Section 4.8)

8. General room exhaust systems should consider emergency exhaust provisions to divert normally recirculated air to the exterior in case of chemical spills. (Section 4.10.2)

9. Exhaust hood air should not be recirculated. (Section 4.10.3)

10. Supply air systems should be fitted with filters with an efficiency > 60% per ASHRAE Dust Spot test; higher efficiencies should be considered if spore or particulate removal is critical. (Section 4.12.1)

11. Exhaust air contaminated with toxic particulate should not be recirculated; all laboratory procedures producing such contaminants should be conducted in a fume hood. (Section 4.12.3)

12. Room air balance should be considered "important" for all but extremely critical laboratories, so that no "desirable" air balance category should be considered. Room air balance monitors installed in "critical" laboratories should be designed and located to allow for reasonable access by laboratory personnel. (Section 4.14.6)

13. Visual inspections on "important" laboratories should be done monthly, but

weekly inspections should be done in "Critical" areas. (Section 4.14.7)

14. Laboratory fume hoods manufactured from combustible materials should not be permitted for fire safety reasons, so fiberglass fume hoods would be proscribed. (Section 5.1)

15. The "recognized good design features" should be MANDATORY for all fume hoods. (Section 5.2)

16. The paragraph on Supply Air Distribution underscores the reliance of the furnisher of the fume hood, and its ultimate performance, on the HVAC system design and installation. Therefore, the complete fume hood installation should be specified in the HVAC section of the specification to coordinate this vital relationship. (Section 5.3)

17. Hoods should not be located side by side, and shall have a 5'-0" minimum width aisle if located opposite each other. (Section 5.4)

18. The phrase "that might be a source of emission (including in case of breakage)" should be deleted from this paragraph. (Section 5.5 (c))

19. Fume hood base cabinets meeting the requirements of ANSI/NFPA 30 and 45 should be considered for all installations. (Section 5.5(d))

20. In addition, the following criteria for sash position should be made mandatory:

    A) Hood sash may not be placed in full open position while an experiment is in progress, but should be closed to at least the height (in case of vertical sash) which brings the sash bottom below the shoulder line of the hood operator.

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B) Hood sash may be placed in full open position (in case of vertical sash) only when moving large objects in and out of the hood.

C) Each hood shall be posted with a notice indicating that the operator must position the sash (whether vertical or horizontal) in a location which will shield completely his or her torso from the shoulder line up at all times while an experiment is in progress. (Section 5.5(f))

21. All fume hoods should be specified to be tested in accordance with ANSI/ASHRAE 110, and rate 4AM 0.05 in the manufacturer's laboratory. (Section 5.6.1)

22. All fume hoods should be subjected to performance tests in the institution's laboratory based on SEFA 1.1-1994, section 7, except that cross drafts shall not exceed 50 percent of the specified average face velocity. A nominal face velocity of 90 FPM, with no single point reading 15% above or below the resultant average, should be used as the norm for all but perchloric acid and HEPA filter radioisotope hoods. (Section 5.6.2)

23. Except for applications in closely monitored facilities, variable air volume hoods should not be installed until they are proved through experience to be dependable and maintainable for universal application. (Section 5.10)

24. Provision (d) should be modified to indicate that perchloric acid fume hoods should not be manifolded or joined to any other hood or hood system, but should be individually vented. (Section 5.12)

25. The use of walk-in fume hoods should be discouraged, since proper air

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movement through the hood is difficult, if not impossible, to achieve. (Section 5.13)

26. The use of ductless fume hoods should be discouraged since these devices are generally not constructed of fireproof materials, and are not fitted with explosion proof motors and electrical devices. (Section 5.16)

27. The design of fume hood ductwork should be modified to reflect the realities of higher education facilities:

    A) All ductwork serving high level radioisotope hoods (i.e. hoods with HEPA filters) and perchloric acid hoods should be installed vertically inside the building (no exceptions).

    B) All ductwork serving all other types of fume hoods should be installed in essentially vertical fashion, with offsets limited to 45 degrees; horizontal ducts, or ducts with offsets greater than 45 degrees, should not be allowed in new construction.

    C) Each fume hood duct should be run separately to the exterior of the building on the roof; fume hood ducts should not be joined inside a building. (Section 6.1)

28. Unless specific applications required special duct materials, all fume hood ductwork should be heliarced stainless steel, type 316; perchloric acid hoods should be fitted with 16-gage, and all others 18-gage material. (Section 6.2)

29. Exhaust fans for fume hoods should be located outside the building on the roof. All fans should be spark resistant construction, and should be coated with

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appropriate chemical resistant materials. All motors should be totally enclosed air over type, except fans serving perchloric acid hoods should be fitted with explosion-proof motors. <u>All stainless steel construction (i.e. both housing and wheel) for perchloric acid hood fans should be specifically prohibited.</u> (Section 7)

30. All manifolding of fume hood ducts should occur on the roof. Manifolding in the building should be prohibited. (Section 7.1.1)

<u>Observations and Additional Suggestions</u>

Updating the Board of Regents's Fume Hood <u>Design Criteria</u> is relatively easy, when compared to the problem of implementing and paying for the costs - both monetary and personal - associated with the new regulations. If these suggestions were adopted by the Regents, project costs would rise for all laboratories with fume hoods, and significant monitoring and maintenance tasks would be inherited by each institution. New building budgets may be able to absorb increased costs, but the ability of each institution to afford to implement such costs in existing facilities through normal funding, including Major Repair and Rehabilitation funding, (MRR) is doubtful. It is also probably safe to state that retrofitting all existing laboratories to current standards is not only physically but financially impossible to achieve. Based on these observations, the following additional suggestions are offered:

a) Primary responsibility for chemical Fume Hood safety should be vested in each institution's Safety Division.

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b) New buildings should not be accepted by an institution until an HVAC Commissioning Report is received, verifying that all fume hoods operate in accordance with the new Criteria.

c) Standard one-year construction guarantee should include quarterly visits by the Contractor to verify in writing that fume hoods continue to operate safety.

d) A formal and routine preventive and repair/replacement maintenance program for hoods should be established at each institution.

e) Each researcher, principal investigator, instructor or any other individual allowed or required to perform experiments in a chemical fume hood should receive specific training on the safe operation of fume hoods from the institution's Safety Division.

f) Consultants should certify that their design for laboratories on new buildings (including major renovation projects) meets or exceeds all Criteria requirements before receiving approval to advertise their project for bidding, and recertify their design upon completion of all work by the Contractor.

g) In the case of minor laboratory renovations, whether done "in house" by an individual institution or with consultants, Criteria should be followed where practical and cost-effective. A written risk assessment narrative should be prepared by the appropriate designer to justify the ultimate design decisions if they vary from requirements of Criteria.

h) Existing fume hood installations should be reviewed on an individual basis. The following conditions should be met within a reasonable period of time (if not already provided):

1. An audible alarm should indicate when low air flow is detected ugh the hood.
2. Baffles shall be adjusted to provide uniform air flow through the hood.
3. Fume hood blowers should be set to deliver a maximum of 100 FPM face velocity at all hoods (except perchloric acid and high level radioisotope hoods-these should have 125 FPM maximum); minimum average velocities shall be no less than 90% of these values.
4. All fume hood fans should exhaust air at a velocity of approx. 4000 FPM, and should be at least 10'0" above the roof (or adjacent roof if within 100 feet).
5. Fume hoods should be retagged on an individual basis to indicate revised (if applicable) face velocities. Also the label indicating the fume hood operator's responsibilities should be attached.

i) Some of the additional work imposed by these revised criteria

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may be beyond the present capabilities of existing institutional personnel; consideration should be given to outsourcing such activities on a temporary or permanent basis.

Conclusion

Higher education institutions require teaching and research science laboratories to fulfill their mission, and therefore have a duty to provide a safe environment for students, faculty and staff members who use these facilities. Chemical fume hoods provide a significant measure of safety for all laboratory users, and these hoods must be selected, installed and operated carefully to help achieve the level of safety required. A set of Criteria, similar to The American National Standard for Laboratory Ventilation, should be adopted and followed by each institution, so that all appropriate electrical, mechanical and human fume hood controls are employed to promote a safe laboratory environment.

Finally, facilities managers, architects, engineers and laboratory consultants cannot be assured that a well-conceived laboratory ventilation system will be used properly. All the best design features and electrical and mechanical controls will not prevent a fume hood accident if the hood operator is negligent or untrained in hood safety. At the risk of incurring the wrath of all members of all chemistry departments, it should be noted that the publication by the American Chemical Society "Safety in Academic Chemistry Laboratories" devotes only 4 pages to facilities, while the discussion on human controls and procedures takes over 30 pages.

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ENDNOTES

1. The State of Maryland recently published a Technical Bulletin "Science Laboratories and Indoor Air Quality in Schools". While written for K-12 schools, this bulletin affords the reader an excellent overview of the "problem"; the following sentence captures its essence:

   > "The subject of indoor air quality and laboratory facilities is quite complex and necessarily crosses over into the even broader of more complex issues of laboratory health and safety."

2. Several manufacturers have prepared excellent literature on the integration of electrical energy/building management control systems with fume hood/fan systems. Such literature, especially from Landis & Gyr, Phoenix, TSI, Strobic Air, Barber-Colman, Hamilton, Kewaunee and Anemostat Companies, has made a significant positive impact on improved laboratory design.

3. Significant progress has been made in the past few years on computer models for predicting airflow both in the laboratory and around buildings. This new field of computational fluid dynamics was described in Engineering News Record recently, and the resultant graphic simulations produced by these models are clearly the wave of the future. Chapter 14 in the ASHRAE Manual on Fundamentals covers building modeling elegantly.

4. Ganged or manifolded fume hood design was first proposed for a University of Georgian project in the mid-1980s by Earl Walls Associates, laboratory consultants to

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CRS Sirrine Company, designers of the University's Life Sciences Building. Such systems were not approved then, due to a lack of experience with them in non-industrial settings. Recent success with these systems has prompted designers in the academy to promote their use.

5. An excellent discussion of factory and laboratory fume hood testing procedures is included in Laboratory Fume Hoods by Saunders. This publication suggests modifications to printed test standards which may prove to be appropriate in the future. For the present, however, it is suggested that the Regents's guidelines follow such printed standards for these two separate functions.

6. Two recent articles highlight the need to consider a systems approach to the design and installation of fume hoods, and the absolute necessity for each new building HVAC system to be "Commissioned". It is highly probable that specifying hoods in the mechanical section will promote these ends. See "Taking a Systems Approach to Fume Hood Design" in the November 1994 edition of Consulting - Specifying Engineer, and "Building Systems Commissioning and Total Quality Management" in the September 1994 edition of ASHRAE Journal.

7. There are exceptional publications available that address all or part of this inchoate field of design and safety. In addition to the Saunders book mentioned in endnote 5 above, other major works include Furr's CRC Handbook of Laboratory Safety, Cooper's Laboratory Design Handbook, the ACGIH Manual, ASHRAE's Manuals, and the Ashbrook, Braybooke and Deberardinis books listed in the Bibliography.

8. The 30 recommendations to revise the ANSI/AIHA Z9.5 - 1992 Standard, and the

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Observations and Additional Suggestions that follow the recommendations, are based on experience, many references, and reports (many admittedly anecdotal) accumulated over the years by one engineer/educator. All reviewers are encourage to challenge each recommendation and suggestion, and to add other suggestions where necessary, in order to develop appropriate fume hood guidelines for his or her institution..

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